About Characteristics of the Induction Motor

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***Abstract* — The aim of this paper is to study the basic characteristics and dependencies of an induction motor. The shaft speed and torque are studied under variation of voltage, frequency and current supplied to the stator windings of an induction motor with short-circuited rotor. The voltage and current of the induction motor were varied by switching from star to delta circuit and the frequency was varied using a three-phase frequency converter.**

***Keywords* — induction motor, revolutions, shaft torque, frequency converter.**

I. INTRODUCTION

Induction motors are characterised by reliable operation, relatively simple construction, direct supply from the AC mains and the absence of special maintenance requirements. These advantages explain their widespread use in all sectors of industry. Induction motors operate on the principle of the interaction of two rotating magnetic fields, one inducing in stator and the other induced in rotor. The induced field determines the angular speed of the rotor. The induced field always has a smaller angular velocity than the inducing field. The difference in angular velocity between the two fields is called slip.

Two basic types of induction motors are distinguished:

- cage induction motor (short-circuited rotor);
- wound rotor induction motor.

Speed regulation in electric drive:

The term speed control refers to the forced change of speed imposed by the requirements for normal operation of the working machine. This change is different from that due to a change in the load of the motor. In speed control, the control action is either operator or automatic. There are various ways of adjusting the speed of electric motors in electromechanical systems by obtaining artificial (control) characteristics [1] - [4].

The main metrics for evaluating the capabilities of different speed control methods are:

a) control range D - ratio of the possible maximum speed ω_{max} to the minimum speed ω_{min}, or

$$D = \frac{\omega_{max}}{\omega_{min}}, \tag{1}$$

[1]b) smoothness of regulation $K_{sm,}$ - ratio of two adjacent speeds ω_i and ω_{i-1} when passing from one regulation characteristic *i* to the nearest adjacent *i-1* , i.e.

$$K_{sm} = \frac{\omega_i}{\omega_{i-1}}; \tag{2}$$

c) economy of regulation η - characterizes the energy losses in regulating the speed of the electric drive, i.e.

$$\eta = \frac{P_2}{P_2+\Delta P}, \tag{3}$$

where P_2 is the motor shaft power;

ΔP - power losses in the electric drive during speed control;

d) direction of adjustment - indicates whether the artificial characteristics are located below or above the natural mechanical characteristic;

e) stability at set speed - related to the stiffness of the mechanical characteristic of the motor in the electromechanical system and takes into account the variation of speed as the load changes;

f) permissible load of the motor under speed control and permissible electric current of the motor under heating conditions [5], [6].

The electric motor will be best used in regulation when the load current I_l for all regulation characteristics is equal or close to the rated current. This assumes the cooling of the electric motor for all speeds remains constant.

The speed control capabilities of AC motors are based on their electromechanical properties. The various methods of speed control for induction motors can be divided into two main groups:

- Parametric methods, for example by varying the active, inductive or total stator and rotor resistance, the magnitude and symmetry of the supply voltage, switching the motor pole pairs;
- Special methods, e.g. using pulse controllers, frequency converters, cascade circuits, multi-motor electric drives [7] - [10].

Of the first group of speed control methods, the modification of the active resistance (insertion of additional resistors) is of the greatest practical importance in wound rotor motors. In the case of electric motors with short-circuited or squirrel-cage rotors, the method of varying the magnitude of the supply voltage is used. Due to the relatively narrow range over which the speed can be adjusted, voltage control is most commonly used with short-circuited rotors and increased slip (i.e. a higher value of rotor resistance is set at the factory, making the characteristics soft and the speed adjustable over a wide range). A common disadvantage of parametric methods is soft mechanical characteristics. For small variations in load M_c, the speed ω varies over a significant range.

To compensate for this disadvantage, closed-loop

Received: 19.09.2024
Published: 30.09.2024
https://doi.org/10.47978/TUS.2024.74.03.003

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electrical drive systems are most often used - feedback loops are applied. These systems are considered in the theory of automated electric drives.

Of the second group of methods for controlling the speed of induction motors, the one of greatest practical importance is the use of frequency converters. In addition to varying the frequency of the supply voltage, the magnitude of the voltage is varied to varying degrees depending on the nature of the load. Frequency regulation is carried out in various modifications, the mechanical characteristics being straight lines parallel to the natural (in the area of use).

The speed of synchronous motors is controlled by changing the frequency of the supply voltage.

Practical applications for speed regulation of induction motors have found

(a) parametric control, where the speed is controlled by changing some parameters of the motor or its circuits - changing the active or inductive resistance in the rotor, changing the number of poles, pulse control, etc;

(b) means of regulation involving the supply of a separate adjustable power source to the motor. Of greatest practical interest is the frequency control of the motor [11] – [13].

II. Experimental Part

In order to achieve the objective of this report, the following investigations were carried out: a three-phase induction motor (IM) model Saerle LS100LT, a mechanical load brake of an IM with variable load by means of a tensioner, and a frequency converter model "Siemens Micromaster 420". The three-phase motor has the following data: power - 0.13/0.07 kW Δ/Y; voltage - 400/400 - Δ/Y; current - 1.70/0.70A; revolutions per minute – 330 / 250 min^{-1}.

The inverter is set from a control panel and controlled by built-in buttons. When the IM is switched on for the first time, the parameters from the motor nameplate, the control model, acceleration times for starting and deceleration times for stopping, minimum and maximum output frequency, slip compensation are set in the inverter. The electrical diagram of the setup is shown in Figure 1.

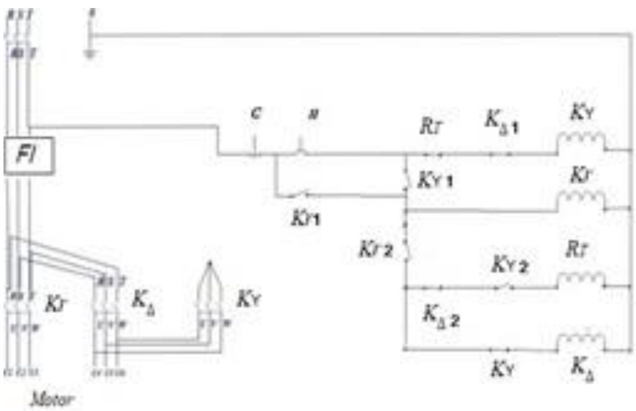

Fig. 1 Schematic diagram of the frequency inverter unit.

where: FI - Frequency converter; K_r- power contactor; K_Δ - power contactor closing the circuit in the "triangle" operating scheme; K_Y - power contactor that closes the circuit in the "star" operating scheme.

The implemented circuit operates as follows:

The installation is powered by a three-phase plug connected to the mains. Depending on how the time relay is connected, we select the operation of the circuit. We select the operation in "star" or "triangle" circuit or in automatic mode. The power contacts of the frequency converter are connected to the contactor K_r. The motor terminals are connected to contactors $K_r$and K_Δ. Contactor K_Y is activated when the circuit is switched to star operation. In the settings of the frequency converter, the frequency values of the supply voltage are set to 10Hz and 50Hz. The frequency, start and motor parameter changes are set from the control panel of the frequency converter. The "Start" button activates the operating circuit of the "Star - Triangle" auxiliary circuit. The developed auxiliary circuit can also operate independently as a star-triangle starter without using an converter. Immediately after power is applied via an ACB, the drive is in standby mode and is started from the control panel.

The circuit thus designed is made up of a circuit breaker, three contactors and upgrades with operating contacts, a "start-stop" button and a time relay (star triangle). The principle of operation of the circuit is as follows: we select the time to trip the time relay. We select the time according to the needs of the research or the time needed to unwinding the engine and then we switch to the operation of the connection in "Triangle". The circuit is then energised by tripping the circuit breaker. Press the start button. Voltage is applied to coil K_Y, closing normal open contact K_{Y1}, voltage is applied to coil K_r, closing normal open contact K_{r1}, closing normal open contact K_{r2}, closing normal open contact K_{Y2} and voltage is applied to the relay timer coil. The normal closed contact K_Y is open and no voltage is applied to the contactor coil K_Δ. In the star connection scheme, after the time has elapsed, voltage is applied only to the coils of the contactors K_r and the contactor K_Δ via the contactors K_{r1} and K_{r2} and the normally closed contact K_Y. This circuit prevents the contactors from being tripped for star operation when the start button is pressed again, which in turn prevents the circuit from short-circuiting two phases. Operation of the circuit is interrupted by pressing the stop button.

III. Results of experimental studies

A study is made of the dependence of the revolutions *(n)* on the load *(M)* at different values of the slip compensation S_k = (0%Hz, 0.5%Hz, 2.5%Hz) for values of the set frequency f_{set}=10Hz and f_{set}=50Hz.

The dependencies are plotted at different loads on the mechanical brake (the experiment uses five different masses for loading). The measurements and the graphs are plotted according to the set frequency and frequency correction (Sk = 0% Hz, S_k = 0.5% Hz, S_k= 2.5% Hz).

The transducer frequency is set at 10Hz to capture the mechanical characteristics. The slip compensation S_k is set in the corresponding menu of the transducer. The motor is loaded with the brake from M ≈ 0. For S_k>0, the frequency *f* should increase as the load increases.

TABLE I

$f = 10Hz,\ S_K = 0$						
Mcn.	*N.m*	0	0.032	0.12	0.22	0.58
U	*V*	70	65	63	56	58
I	*A*	0.73	0.74	0.81	0.80	0.72
n	min^{-1}	92	92	88	74	64
M	*N.m*	2.54	2.39	2.65	2.78	2.99
P	*kW*	0.02	0.02	0.02	0.02	0.02
F	*N*	0	4.31	16.57	28.84	77.89

TABLE II

$f = 25Hz,\ S_K = 0$						
Mcn.	*N.m*	0	0.032	0.12	0.22	0.58
U	*V*	140	155	134	141	176
I	*A*	0.99	1.01	1.06	1.09	1.06
n	min^{-1}	206	206	200	200	190
M	*N.m*	3.09	3.48	3.26	3.52	4.50
P	*kW*	0.07	0.075	0.068	0.073	0.089
F	*N*	0	4.31	16.57	28.84	77.89

TABLE III

$f = 50Hz,\ S_K = 0$						
Mcn.	*N.m*	0	0.032	0.12	0.22	0.58
U	*V*	350	360	376	383	387
I	*A*	0.96	1.00	1.07	1.06	1.04
n	min^{-1}	570	575	570	550	540
M	*N.m*	2.85	2.85	3.18	3.32	3.42
P	*kW*	0.16	0.17	0.19	0.20	0.19
F	*N*	0	4.31	16.57	28.84	77.89

TABLE IV

$f = 10Hz,\ S_K = 0.5\%$						
Mcn.	*N.m*	0	0.032	0.12	0.22	0.58
U	*V*	57	73	53	48	42
I	*A*	0.78	0.76	0.76	0.86	0.67
n	min^{-1}	96	94	88	80	50
M	*N.m*	2.12	2.31	2.21	2.37	2.58
P	*kW*	0.02	0.27	0.02	0.02	0.01
F	*N*	0	4.31	16.57	28.84	77.89

TABLE V

$f = 25Hz,\ S_K = 0.5\%$						
Mcn.	*N.m*	0	0.032	0.12	0.22	0.58
U	*V*	158	147	166	131	171
I	*A*	1.05	1.04	1.03	0.98	0.97
n	min^{-1}	206	206	202	202	195
M	*N.m*	2.91	3.39	3.58	3.91	3.98
P	*kW*	0.079	0.073	0.0820	0.0616	0.0796
F	*N*	0	4.31	16.57	28.84	77.89

TABLE VI

$f = 50Hz,\ S_K = 0.5\%$						
Mcn.	*N.m*	0	0.032	0.12	0.22	0.58
U	*V*	347	371	391	389	340
I	*A*	1.03	1.01	1.00	1.01	0.99
n	min^{-1}	580	580	575	550	540
M	*N.m*	2.825	2.962	3.091	3.255	3.152
P	*kW*	0.171	0.179	0.187	0.184	0.161
F	*N*	0	4.31	16.57	28.84	77.89

TABLE VII

$f = 10Hz,\ S_K = 2.5\%$						
Mcn.	*N.m*	0	0.032	0.12	0.22	0.58
U	*V*	53	55	62	51	61
I	*A*	0.73	0.79	0.79	0.77	0.75
n	min^{-1}	96	94	92	88	58
M	*N.m*	1.848	2.119	2.441	2.304	3.617
P	*kW*	0.0185	0.0208	0.0235	0.0188	0.0219
F	*N*	0	4.31	16.57	28.84	77.89

TABLE VIII

$f = 25Hz,\ S_K = 2.5\%$						
Mcn.	*N.m*	0	0.032	0.12	0.22	0.58
U	*V*	124	134	139	126	147
I	*A*	1.01	1.06	1.06	1.05	1.03
n	min^{-1}	208	208	202	202	190
M	*N.m*	2.760	3.131	3.244	3.161	3.6544
P	*kW*	0.0601	0.0681	0.0707	0.0635	0.0726
F	*N*	0	4.31	16.57	28.84	77.89

TABLE IX

$f = 50Hz,\ S_K = 2.5\%$						
Mcn.	*N.m*	0	0.032	0.12	0.22	0.58
U	*V*	392	396	394	398	397
I	*A*	1.03	1.04	1.07	1.02	1.07
n	min^{-1}	580	573	570	560	550
M	*N.m*	3.106	3.272	3.352	3.4659	3.578
P	*kW*	0.193	0.197	0.202	0.194	0.203
F	*N*	0	4.31	16.57	28.84	77.89

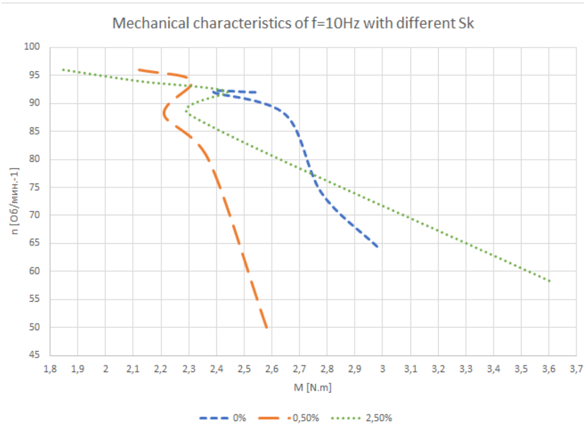

Fig. 2. Mechanical characteristics at f = 10 Hz and different values of S_k.

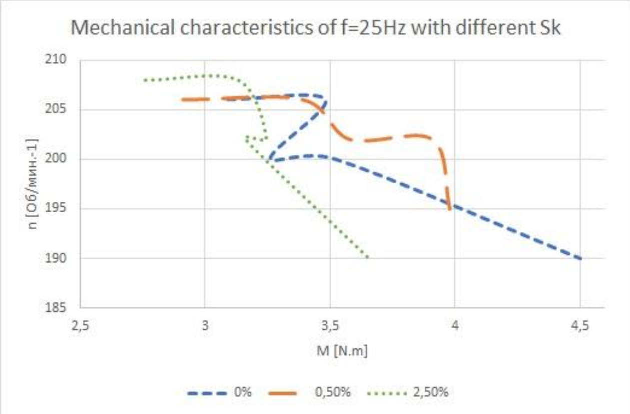

Fig. 3. Mechanical characteristics at f = 25 Hz and different values of S_k.

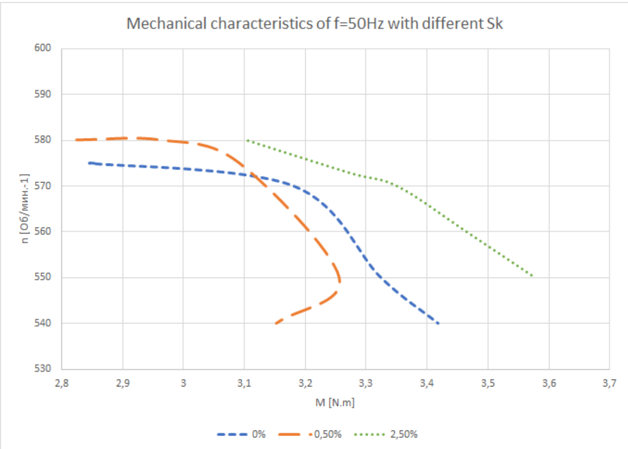

Fig. 4. Mechanical characteristics at f = 50 Hz and different values of S_k.

IV. Conclusion

1. The dependence of the revolutions (n) on the load (M) of an induction motor with a short-circuited rotor is studied and the results of the study are presented in tabular and graphical form.

2. The active power consumed increases as the load increases, but as the frequency of the supply voltage decreases for the same values of motor load, the active power consumed decreases. This is due to the frequency control, which maintains a constant relationship between voltage and frequency. The electrical energy saving achieved is due to the reduction in the magnitude of the supply voltage and frequency.

3. When the motor is controlled by a frequency converter, the current through the motor varies smoothly at different load values.

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